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Context-aware control of user-centric virtual networks: Centralized vs distributed approaches

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ABSTRACT

Recently, the Internet has been overrun by a diversity of devices, applications, technologies, and Internet users with increasingly demanding personal preferences. Due to the explosive growth of Internet usage, the quantity of context information available in networking environments is also growing rapidly, triggering research for novel architectures and protocols that are enriched or personalized based on the particular features and dynamics of such information.

This article describes a virtualized architecture that splits a physical network infrastructure into a set of logical networks (or Virtual Networks – VNs) configured to meet the particular context needs of their attached users (in terms of, e.g., price, security or services' quality). Since this architecture can be driven by volatile context needs of highly mobile users, we also present the signaling mechanisms to create, extend and remove VNs in response to user context dynamics and mobility, which can be performed in a centralized or distributed way. Further, we define and evaluate context-aware metrics to configure a VN, and discover and select VNs to assign to users or network paths.

The evaluation of the proposed approach shows that distributed approaches allow the fast discovery and adaptation of VNs, at the cost of a slightly larger overhead than centralized approaches when the context dynamics are too high. We also assess the impact of considering distinct levels of knowledge distribution and user context dynamics on the design and behavior of several processes for user association and VN control. Finally, we observe that context-driven VN discovery and resource-aware path selection schemes outperform the ones that, respectively, flood the network with VN discovery requests or use shortest path-based strategies to adapt VNs.

1. Introduction

In modern society, we have witnessed the appearance of user-friendly portable devices, accompanied by the proliferation of high-quality multimedia services and the evolution of network technologies. Mobile users are also increasingly demanding in terms of personal expectations and preferences (e.g., security, price or mobility), desiring Internet connectivity anytime and everywhere. These aspects have triggered many research efforts, since the current Internet is facing unprecedent limitations to provide enough flexibility for end-users, while meeting the requirements of the emerging networking evolution.

Today, and especially in the future, these requirements will play an important role to characterize and/or adapt the way that a particular mobile user accesses the Internet. For instance, they can influence the autonomous selection and change of the: (i) device used by the user, in a particular situation or location, based on his/her preferences and/or user devices' battery capabilities; (ii)

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access network/technology based on the ones available in the user surroundings, and on their status, or on the user mobility behavior; (iii) network resources assigned to the requested service based on the service requirements. In this article, these multi-dimensional aspects will be considered as the context [1] of a user that desires to access the Internet.

In the literature several solutions have been proposed to enhance the current Internet-based architectures and protocols, in order to become context-aware [1], that is, to be dynamically configured and adapted according to the context information that may affect their functionality. These solutions consider the context availability as an opportunity to enrich or personalize several network mechanisms and services.

Fully aligned with this context-aware networking research, the work presented in [2] defined an architecture that builds a set of independent and logical networks over the same physical network infrastructure, each being a logical network configured and personalized to meet the context requirements of a group of users. Network virtualization [3] is used to dynamically create, extend and remove these logical networks (or Virtual Networks – VNs), since it has been identified as a key technology to deploy independent architectures and services towards the Future Internet [4], while allowing a programable and flexible resource management. A significant number of approaches in the literature provide the means to virtualize nodes and networks both in wired and wireless environments, and the work presented in [5] already evaluated the potential of network virtualization to build the aforementioned architecture.

The simultaneous support and dynamic control of multiple VNs, based on the context requirements of users that are constantly entering and leaving the network, are not straightforward tasks. First, VNs have to be configured to meet a particular set of user context needs that can change at a significant rate. Therefore, intelligent mechanisms are required to quantify, model and structure the user context information, and then rules are needed to map such information in proper VN features. Second, whenever the user context information shows some regularities over time, these regularities can be used to improve VN control and management mechanisms. Third, a single VN has to be selected and/or extended on-demand to react to the mobility of its associated users, and this process cannot disregard the presence of other VNs in the network. This way, the autonomic selection and extension of VN structures have to meet a compromise among the user context needs, VN features and network resource availability. Fourth, the mechanisms to discover, create, extend and remove VNs in an autonomic way, and in response to user context changes or mobility, can be performed through centralized or distributed approaches. Centralized approaches have inherent scalability problems, while distributed approaches impose extra network synchronization costs; it is then important to analyze the potential of both approaches to control and manage the multi-VN architecture.

Our work in [2] proposed a platform to distribute the control knowledge and functionalities along the architectural entities. This includes the proposal of signaling mechanisms to autonomously discover, create, extend and remove VNs on-demand based on the cooperation among these entities. Moreover [2] defined an analytical model to evaluate the signaling load of the mechanism to associate a user to an available VN that matches the user requirements, when using a centralized, decentralized or distributed approach, and the overhead of each approach.

This article goes beyond [2] on the design and evaluation of the distributed platform with several context-aware VN management mechanisms. This article first provides the groundwork for the automatic quantification and modeling of the user context requirements in levels, and for the mapping of these levels into suitable VN structures, protocols and resources. Second, it explores the idea of considering levels of flexibility (related to the rate of variation) of the user context requirements to: (i) improve the VN selection by allowing user connections to VNs that are most likely to react to the user context dynamics, decreasing the need to constantly change the VNs assigned to users; (ii) enable the quick and context-driven VN discovery through the dynamic inter-operability of the VNs that are most likely to cope with the user context dynamics. Third, it proposes a resource-aware metric to map the VNs in the physical network infrastructure, aiming to increase the network capacity. Finally, this article contains an overall simulation and evaluation of several distributed and centralized platforms for VN control, and of the mechanisms proposed.

Through an evaluation performed in a wireless mesh scenario, we observe the improvement of context-driven distributed approaches over centralized approaches in terms of user associated delays, at the cost of a slightly larger overhead when the network dynamics is too high. We then assess the gains and drawbacks of considering distinct levels of knowledge distribution and user context flexibility on user associated delays, control overhead, and number of network reconfigurations. Then, we show how the context-aided definition of the VN selection metric can decrease the VN adaptation costs, when required to cope with the user context dynamics. Finally, we demonstrate that the: (i) context-driven VN discovery mechanism clearly outperforms solutions that flood the network with VN discovery requests; (ii) resource-aware path selection scheme significantly improves shortest path-based strategies when it is required to create or extend VNs in the network.

The remainder of the article is organized as follows. Section 2 gives an overview of the related work, while Section 3 presents the architecture that splits a physical network infrastructure into a set of user-centric context-aware VNs. Section 4 then describes a distributed platform to control and manage VNs on-demand. Section 5 defines several rules to model user context into proper VN features, while Section 6 defines the mechanisms and metrics to select, discover and extend VNs. Section 7 evaluates the performance of different strategies to perform the processes for user association and VN control in a centralized or distributed way. Finally, Section 8 concludes the article.

2. Related work

Context, as it is defined in [1], is any type of information that can be used to characterize the situation of network